Enhanced critical currents in superconducting strips with slits

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ABSTRACT

Experiments in flat strips of the high-temperature superconductor $Bi_2Sr_2Ca_1Cu_2O_x$ (Bi-2212) have shown that an edge barrier of geometrical origin dominates the critical current (i.e., the current at the onset of a dc voltage) over a wide range of temperatures and magnetic fields. We have extended our earlier theory of the geometrical-barrier critical current by investigating the penetration of magnetic flux into a superconducting strip with longitudinal slits. We found that the critical current of a strip with 2*N* slits in zero applied magnetic field can be enhanced by a factor as large as $(N+1)^{1/2}$ above that of a single strip without slits.[1]

1. Y. Mawatari and J. R. Clem, "Magnetic-Flux Penetration and Critical Currents in Superconducting Strips with Slits," Phys. Rev. Lett. **86**, 2870 (2001).

The critical current I_{cs} in a single strip (width $2a$, thickness $d << a$, infinitely extended along the z-axis) without bulk pinning is calculated as follows. It is convenient to express the two-dimensional field distribution as an analytic function $H(\zeta) \equiv H_y(x,y) + iH_x(x,y)$ of the complex variable $\zeta \equiv x + iy$. When the strip carries a transport current I_t along the z-axis in the absence of an applied magnetic field, the complex field around the strip is $H(\zeta) = (I_t / 2\pi)(\zeta^2 - a^2)^{-1/2}$. The magnetic field at the edge is approximately $H(a+\delta) = (I_t / 2\pi)(2a\delta)^{-1/2}$, where δ is a cutoff length on the order of the thickness d. The critical current I_{cs} for the strip without bulk pinning is the current I_t at which $H(a+\delta)$ reaches a certain flux-entry field H_s, which is equal to the lower critical field H_{c1} in the absence of a Bean-Livingston barrier or which may be as high as the thermodynamic critical field H_c in the presence of an ideal surface barrier. The result is $I_{cs} = 2\pi H_s (2a\delta)^{1/2}$.

We used an extension of the above complex-field approach to calculate the critical current for a strip of width $2a$ containing longitudinal slits as shown in Fig. 1. The results are shown in Fig. 2.

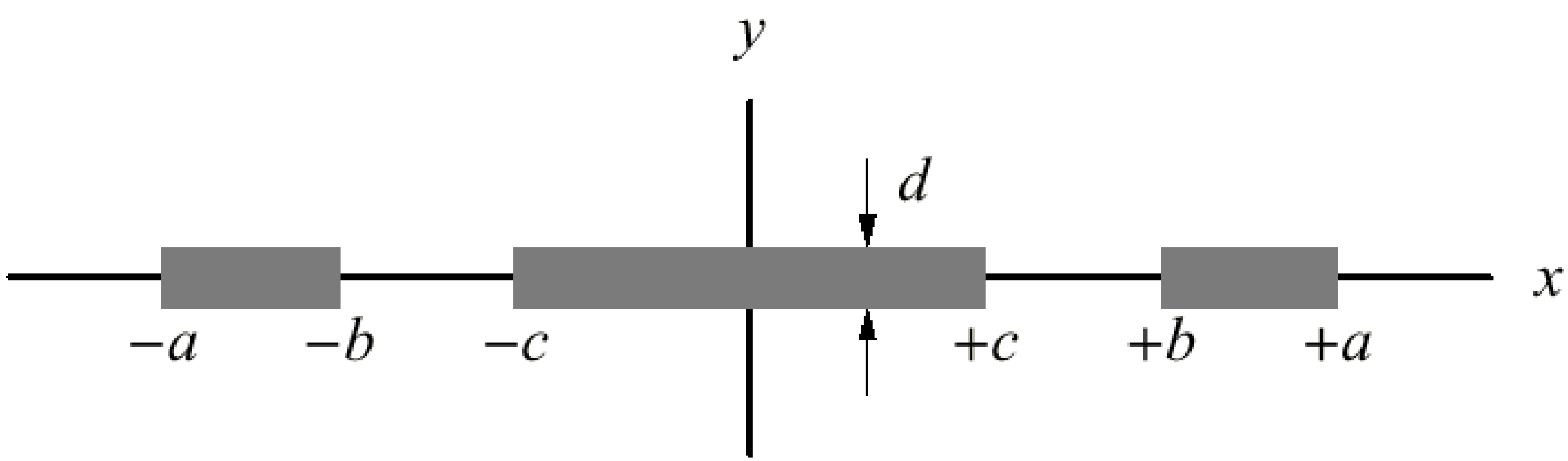

FIG. 1. Superconducting strip with two slits (N = 2). Superconducting strips (thickness d, $|y| < d/2$, infinitely extended along the z-axis) occupy the gray areas: the inner strip is at $|x| < c$, the outer strips are at $b < |x| < a$, and the slits are at $c < |x| < b$. The inner strip carries a net current I_{in}, the two outer strips carry I_{out} each, and the total transport current is $I_t = I_{in} + 2I_{out}$.

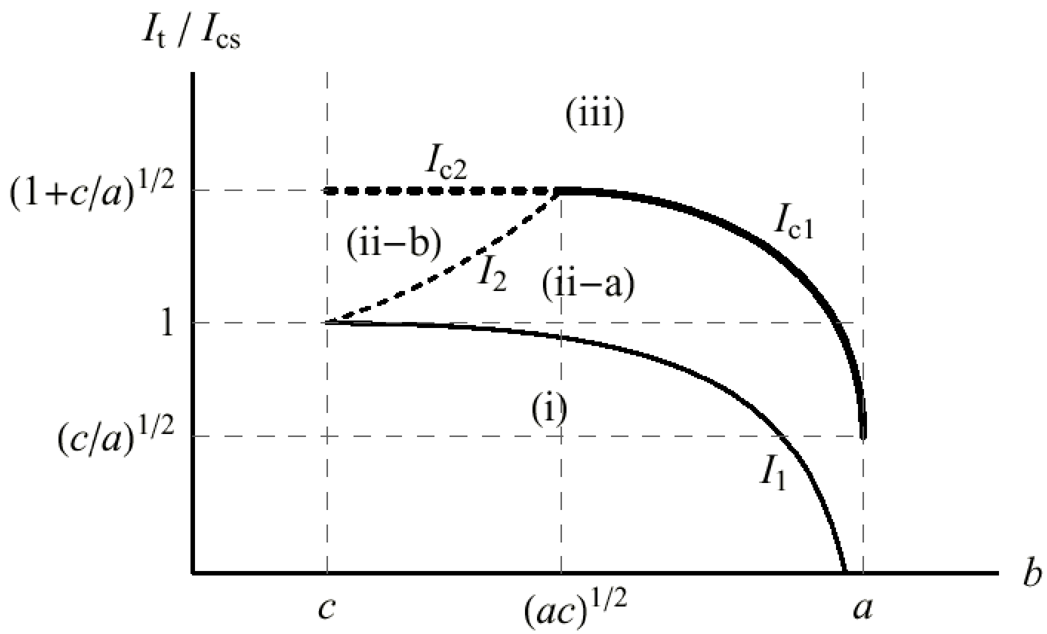

FIG. 2. Region (i) $0 < I_t < I_1$: no magnetic flux penetrates into the strips. (ii) magnetic flux penetrates into slits either (a) *without* or (b) *with* domelike flux distributions in the outer strips, but no flux penetrates into the inner strip. (iii) $I_t > I_c$ [where the critical current I_c is given by $I_c = I_{c2}$ for $b < (ac)^{1/2}$ and $I_c = I_{c1}$ for $b > (ac)^{1/2}$: flux continuously penetrates and the flux annihilates at the center, producing a resistive state. Note that $I_c/I_{cs} \approx 2^{1/2}$ when $c \approx a$.

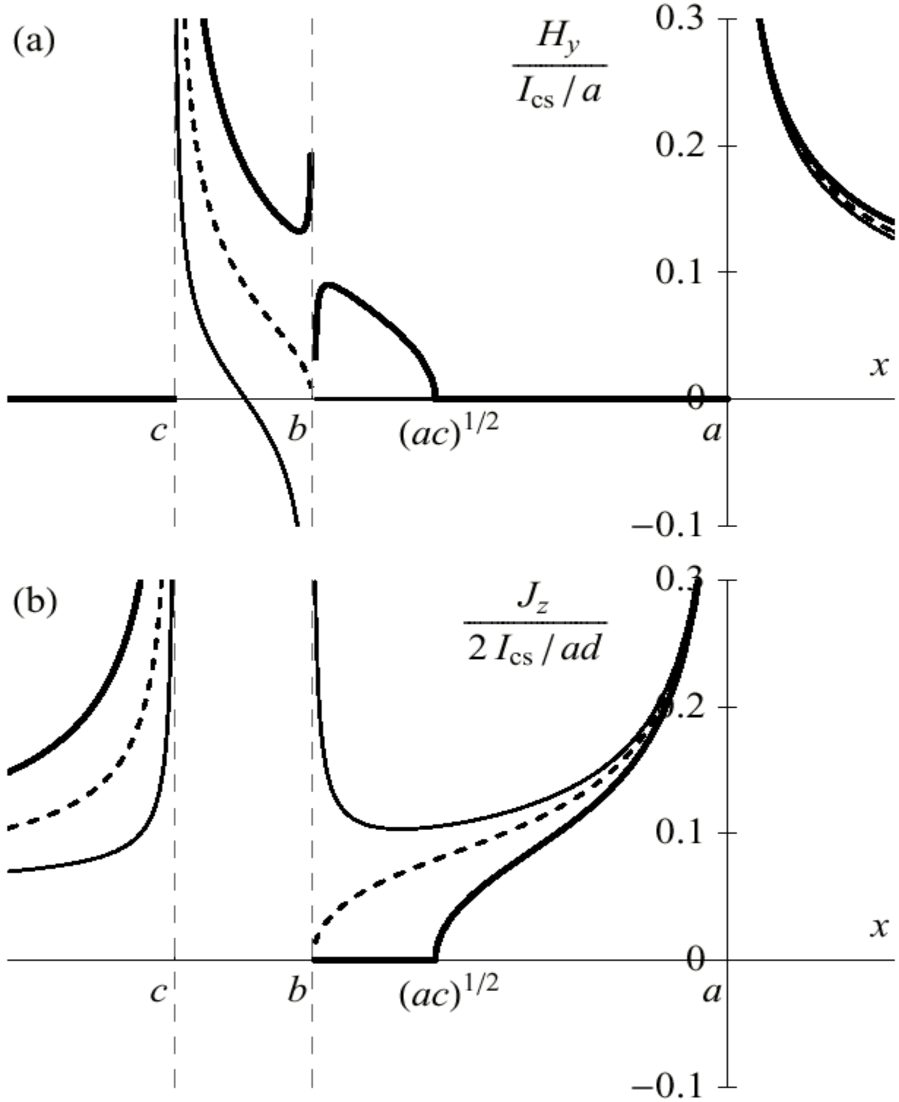

FIG. 3. Distributions of (a) the magnetic field $H_y(x,0) = \mathrm{Re}[H(x)]$ and (b) the current density $J_z(x) = (2/d)\mathrm{Im}[H(x)]$ at $y = 0$ for $I_t = I_1$ (thin solid), $I_t = I_2$ (dashed), and $I_t = I_{c2}$ (bold solid) [see Fig. 2]. Note for the latter case that (a) there is a domelike flux distribution in the outer strip and (b) the current density is zero under the dome. The distributions are calculated from equations given in Ref. 1.

SUMMARY

- Since to calculate the magnetic field around a long superconducting strip with slits is a two-dimensional problem, to solve it we used a complex-field method, in which appropriately chosen analytic functions describe the complex magnetic field.

- With two slits ($N = 2$) close to the edges, we showed in Ref. 1 that the critical current (the current at the onset of a voltage along the length of the strip) is enhanced by approximately a factor of $2^{1/2}$.

- By extending our approach to the case of $2N$ longitudinal slits, we showed in Ref. 1 that the critical current could be enhanced by a factor as large as $(N + 1)^{1/2}$.

- When slits are present, the outer edges of the strips act as pinning centers, penetration of magnetic flux is delayed, and the critical current is enhanced.